Overview of Highly Accurate RF and Optical Frequency Standards at the National Research Council of Canada

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The recent spectacular developments in Frequency Standards technology and techniques have provided an unprecedented advance in accuracy and stability which are now moving into the 10^{-17} level. As part of the worldwide activity in this area, our group at the National Research Council has been working to develop, exploit, and refine these new technologies in both the optical and radio frequency regimes for metrological and precise scientific studies.

In the last few years, our group has worked toward the creation of a Cs fountain standard which will serve as the primary realization of the SI second for Canada and give us the ability to compare our next generation optical frequency standards with a primary realization of the SI second targeted to be at the 1×10^{-15} level. The new fountain incorporates different cooling geometries (110 beam orientations for the MOT), cavity structures (E-field aligned rectangular TM_{210} cavities), a transverse C-field configuration, and an electro-static shutter system. With such features, it is envisaged that the standard can be operated with multiple collections of Cs atoms travelling in the drift region with the minimum perturbation and dead times. Recent modifications of the fountain design have now permitted the temperature variation and control of the C-field drift region to allow for detailed measurements of the blackbody shift.

Since 1989, our group has been studying a single laser cooled $^{88}Sr^+$ ion probed on the 0.4 Hz natural linewidth, S-D 445-THz electric quadrupole allowed transition. Based on our work and that of the NPL (UK), the standard has been refined to the point that the system is now an internationally recognized secondary realization of the second. It is foreseen that the ion based standard will be able to reach beyond the current measured accuracies to the 10^{-17} level. Much of the current work has been directed to the refinement of the probe and cooling laser sources based on commercial diode laser technology combined with ultra-high finesse and isolated optical cavities. To date, spectral linewidths of 5 Hz of the S-D reference transition and drift rates of 10-20 mHz/s have been observed using the current laser source with probing periods exceeding 24 hrs. Recent developments will be described concerning our new trapped ion facility which allows increased control of ion micromotion, improved background field stability and lower systematic shifts. An important element in the realization of accurate time/frequency standards is the connection of such sources to the radio frequency regime using frequency comb technology. Our Titanium-Sapphire based frequency comb has allowed us to determine the transition frequency of the Sr^+ ion to a level of 15 Hz and has been extended from the visible/near IR to the measurement of 1.5 μm standards stabilized on reference lines in the isotopes of acetylene. Such lines are now the operating recommended frequencies for this region of the spectrum setting the basis for traceable measurement in telecom sources. In addition, we have developed an Er-fiber laser based frequency comb which will be able to be operated for extended periods of time without adjustment and provide a reliable, low maintenance link. Since our first demonstration of the measurement of reference lines in C_2HD at 1500 nm, the Er fiber laser comb has been extended to provide linkage at the 445-THz Sr^+ reference frequency and thus a reliable clock-work is obtained for optical-optical and optical rf comparisons. A summary of current progress in this area will be provided together with some views toward future studies.